Modeling and Measuring Acoustic Backscatter from Fish Aggregations

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LONG-TERM GOAL

The long-term goal of this program is to quantify, understand and predict acoustic backscatter from fish aggregations.

OBJECTIVES

Objectives of this project include: quantifying the relative importance of biological and physical factors that influence backscatter from fish aggregations; comparing acoustic technologies used to assess fish abundance; and to acoustically quantify size distributions, abundances, and behaviors of fish.

APPROACH

Acoustic backscatter models utilize digitized x-ray images of fish bodies and swimbladders to predict species-specific echo amplitudes as a function of acoustic wavelength, fish length, and fish aspect. Model predictions of scattering by individuals are used in computer simulations to estimate aggregation abundance and packing densities, and are compared to laboratory and *in situ* field measurements.

WORK COMPLETED

Intra-specific acoustic backscatter variability was examined for freshwater and marine fish species as a function of species, length, aspect angle, and acoustic wavelength. Predicted backscatter models were completed for alewife (*Alosa pseudoharengus*), rainbow smelt (*Osmerus mordax*), lake whitefish (*Coregonus hoyi*), Atlantic cod (*Gadus morhua*), brook trout (*Salvilinus fontinalis*), Namibian pilchard (*Sardinops ocellatus*), and horse mackerel (*Trachurus trachurus capensis*). Predictions from backscatter models were compared to measures of American and New Zealand eels (*Anguilla* sp.), chinook and sockeye salmon (*Oncorhynchus* sp.), and lavnun (*Ancanthobrama*

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terraesanctae). Collaborations are underway to model and measure backscatter from Atlantic herring (*Clupea harengus harengus*), paddlefish (*Polyodon spathula*), alewife (*Alosa pseudoharengus*), and capelin (*Mallotus villosus*).

We participated in a joint Namibian, Norwegian, and South African cruise off the coast of Namibia to examine schooling behavior and to estimate abundance and biomass of Namibian pilchard and horse mackerel. To compare backscatter model predictions for pilchard and horse mackerel to sonar measurements, fish roll angle was incorporated into the Kirchhoff-ray mode model. An interactive computer visualization written in Interactive Data Language (IDL) depicts the fish body and swimbladder in three dimensions and the 360^o tilt by 360^o roll acoustic ambit at 2^o resolution for any specified frequency.

Three international workshops or conference sessions were organized and conducted in the past year. The third Great Lakes Acoustic Workshop entitled, " Translation of acoustic data to fish abundance" attracted 30 participants from the Great Lakes and New England to the Cornell University Field Station in Bridgeport, New York. A special session entitled 'Theoretical and empirical innovations in fish and plankton acoustics' was held during the joint Acoustical Society of America/European Acoustics Association conference in Berlin during March. A Gulf of Maine/Georges Bank herring acoustics workshop was held at the Northeast Fisheries Science Center in Woods Hole during January.

Eight lectures were presented in conjunction with ongoing research and workshops during 1999. An invitational lecture summarizing the use and application of backscatter models was presented at a fisheries acoustics workshop hosted by Simrad in Seattle. Participation in the workshop resulted in an invitation to join the advisory board for the Scientific Assessment Technologies Laboratory (SATL) at the University in Toronto and to participate in sampling programs that integrate multibeam sonar and global positioning system (GPS) technologies. An invited lecture examining the use of theoretical scattering models for predicting target strength and choice of operating frequency was presented at the third Great Lakes Acoustic Workshop. Three presentations were made at the joint American and European Acoustical Society meeting held in Berlin. Overview lectures summarizing the use and application of backscatter models to fisheries acoustics was presented at the ICES FAST meeting in St. John's, Newfoundland, at the Alaska Fisheries Science Center in Seattle, Washington, at the Pacific Biological Station in Nanaimo, British Columbia, and at the Aquatic Ecology Laboratory at the Ohio State University in Columbus, Ohio.

RESULTS

The interactive visualization of the fish body and swimbladder depicts fish anatomy as it is used in model calculations (Fig. 1). Cylinder resolution used in the visualization ranges from 15 mm to 18 mm relative to the 1 mm resolution used in model calculations. The angle of the swimbladder relative to the sagital axis of the body in most fish species deviates 5-10^o posterior down.

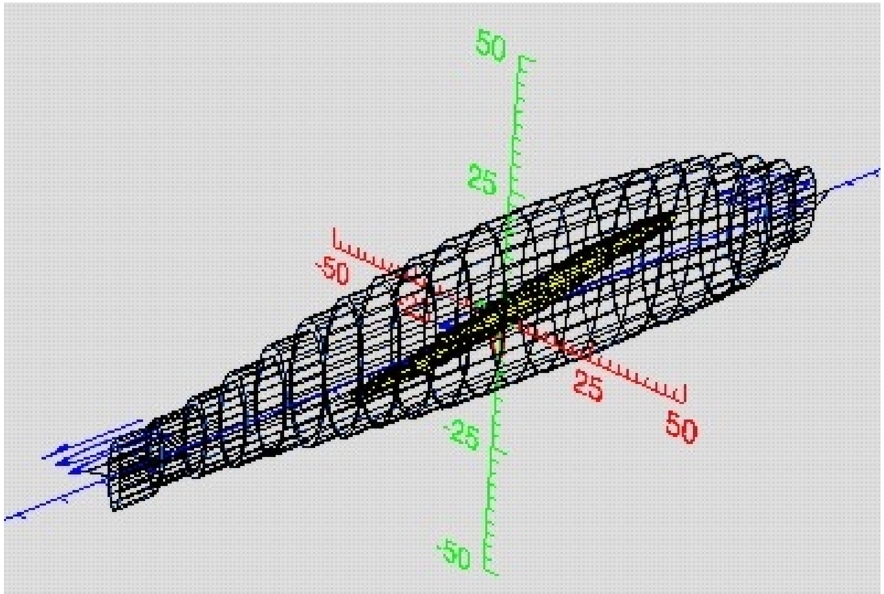

Figure 1. Cylindrical representation of Pilchard body and swimbladder used in Kirchhoff-ray mode backscatter model. The swimbladder is tilted approximately 8^{o} posterior relative to the sagital axis of the fish.

The combination of aspect and roll angles in KRM model calculations enables estimates of acoustic backscatter for 360^{o} tilt by 360^{o} roll angles for individual fish. The three-dimensional aural visualization has been dubbed the fish backscatter ambit (Fig. 2). Backscatter amplitude predictions from the model are stored in a matrix and selected for any user-specified frequency.

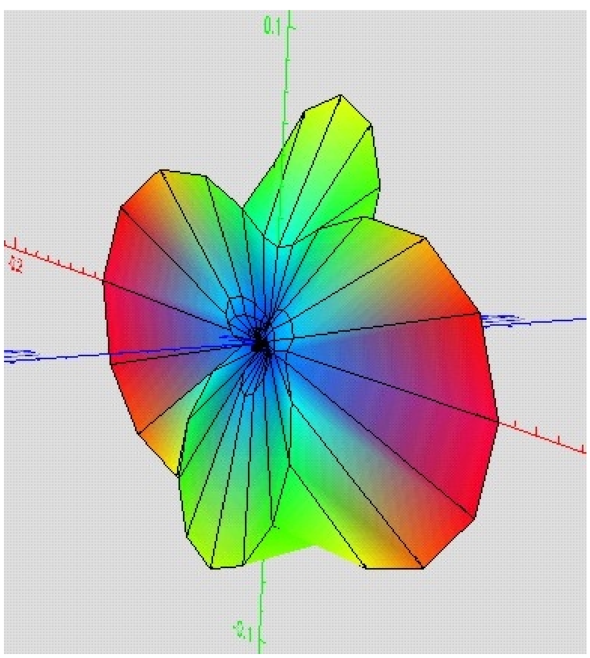

Figure 2. Acoustic backscatter ambit of a 107 mm Pilchard at 120 kHz. Reduced scattering length is resolved at 15^{o} in the tilt plane and 15^{o} in the roll plane. Orientation of the fish matches that in Figure 1. Maximum amplitude occurs when the swimbladder is orthogonal to the incident wave front, which tilts the fish approximately 8^{o} head down.

Acoustic surveys of fish encounter individuals over a range of sizes that are oriented at a variety of tilt and roll angles. Estimates of backscatter from individuals within aggregations are obtained by including probability distributions of roll and tilt angles in KRM backscatter model calculations for a range of acoustic frequencies and fish lengths. Tilt and roll angles are tabulated using theoretical probability distributions, *in situ* visual observations, or inferred from sonar measurements. A target strength (i.e. logarithmic transformed backscatter amplitude) to fish length equation for Namibian pilchard was calculated using normally distributed roll and tilt angles. This equation predicts backscatter values greater than those currently used by Namibian fisheries managers and were closer to values used by the South African fisheries managers. An increase in target strength relative to fish length will reduce acoustic-based fish abundance estimates. These results have prompted Namibian fisheries managers to consider a research program to determine the target strength -- fish length relationships for pilchard.

IMPACT/APPLICATIONS

Our efforts quantify the influence and relative importance of biological and physical factors on the magnitude and variability of acoustic backscatter from fish aggregations. Species-specific backscatter models verified using *in situ* echo amplitude measures provide powerful tools to investigate aural reflective properties of aquatic organisms. Predictions from backscatter models are used to examine techniques and resulting biases in acoustic population estimates. Understanding sources and variability of backscattered sound from fish aids in the discrimination of biologic from anthropogenic acoustic targets.

TRANSITIONS

The extension of the Kirchhoff-ray mode (KRM) model to include organism roll enables the prediction of backscatter amplitude for sector scanning and multibeam sonars. Estimates of acoustic backscatter by individuals or aggregations of fish can now be compiled in probability distribution functions (PDF's) to characterize echo variability due to fish movement and transducer orientation. PDF backscatter predictions combined with backscatter measurements can be used to estimate density, abundance, biomass, and behavior of fish aggregations.

RELATED PROJECTS

Predicted echo amplitude PDF's from individual fish are being compared to those measured from fish aggregations. We are using KRM models to examine backscatter amplitude variability and behavior of pilchard and horse mackerel aggregations in southwest Africa, capelin in the St. Lawrence estuary, and Atlantic herring in the Gulf of Maine.

PUBLICATIONS

Horne, J.K. and Jech, J.M. 1999. Multi-frequency estimates of fish abundance: constraints of rather high frequencies. ICES Journal of marine Science 56: 184-199.

Horne, J.K. 1999. Animal Groups in Three Dimensions. J.K. Parrish and W.M. Hamner (eds.) book review. Journal of Fish Biology 54: 1343-1344.

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Horne, J.K. Acoustic approaches to remote species identification. Fisheries Oceanography (accepted).

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Horne, J.K. Acoustic models and measures of American eels: influences of anatomy, behavior, and frequency. Fisheries Bulletin (submitted).

PRESENTATIONS

Horne, J.K. 1998. Acoustic models, measures, and simulations of fish in the Great Lakes. Invited lecture. Simrad Fisheries Research, Freshwater Acoustic Meeting. Seattle, Washington.

Horne, J.K. 1999. Theoretical scattering models for predicting target strength and the choice of operating frequency: applications to alewife and smelt in the Great Lakes. Invited lecture. Great Lakes Acoustic Workshop III. Cornell Biological Field Station, Bridgeport, New York.

Horne, J.K. 1999. Acoustic approaches to remote species identification. 137th Meeting of the Acoustical Society of America. Berlin, Germany.

Horne, J.K., Jech, J.M. and Walline, P.D. 1999. Comparing predictions from backscatter models to *in situ* measurements of a dual-chamber, swimbladdered fish. 137th Meeting of the Acoustical Society of America. Berlin, Germany.

Jech, J.M. and Horne, J.K. 1999. Multi-frequency measures and models of Lake whitefish (*Coregonus clupeaformis*) backscatter from Lake Michigan. 137th Meeting of the Acoustical Society of America. Berlin, Germany.

Horne, J.K. and Jech, J.M. 1999. Quantifying variability in fish backscatter: Integrating theory and empiricism. ICES Fisheries Acoustics Science and Technology Working Group annual meeting. St. John's, Newfoundland, Canada.

Horne, J.K. 1999. Quantifying distributions and dynamics of aquatic organisms. Invited lecture. Alaska Fisheries Science Center, Seattle, Washington. Pacific Biological Station, Nanaimo, British Columbia.

Horne, J.K. 1999. An overview of acoustic backscatter models and applications to fisheries resource assessment. Invited lecture. Aquatic Ecology Laboratory, The Ohio State University, Columbus, Ohio.

WORKSHOPS AND CONFERENCE SESSIONS ORGANIZED

Great Lakes Acoustic Workshop III: Acoustic size and assessment. 1999. Great Lakes Fisheries Commission, Cornell University Field Station, Bridgeport, NY.

Theoretical and empirical innovations in fish and plankton acoustics. 1999. Joint American Society of Acoustics and European Acoustics Association, Berlin, Germany.

Gulf of Maine Herring Acoustics Workshop. 1999. NOAA/NMFS/NEFSC Woods Hole, MA.